Lagrangian Turbulence and Transport in Semi-enclosed Basins and Coastal Regions

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LONG-TERM GOALS

The long-term goal of this project is the development and application of new methods of investigation for the use of Lagrangian data and for the fusion of these data with other in-situ and satellite information. Special attention is given to the development of new techniques for the assimilation of Lagrangian data in Eulerian numerical models. Another objective is to improve previous results on statistical prediction of particle transport using data analysis and stochastic models.

OBJECTIVES

To develop methods in the framework of the ODDAS DRI objectives, namely to use information from drifting sensors to improve the prediction of spreading in the velocity field. The project has the following specific objectives:

1) To develop and apply new techniques for assimilation of Lagrangian data and of other tracer and velocity data in ocean circulation models.

2) To investigate statistical prediction of particle transport using data analysis and stochastic models.

APPROACH

The work involves a combination of analytical, numerical and data processing techniques. The method development has been carried out in collaboration with L. Piterbarg (USC), A. Molcard (LSEET Universite' of Toulon), P. Poulain (OGS), V. Taillandier (CNR, RSMAS).

1. REPORT DATE **30 SEP 2007**	2. REPORT TYPE	3. DATES COVERED

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Lagrangian Turbulence And Transport In Semi-enclosed Basins And Coastal Regions	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Rosenstiel School of Marine and Atmospheric Science,Division of Meteorology and Physical Oceanography,4600 Rickenbacker Causeway,Miami,FL,33149**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES **10**	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**			

WORK COMPLETED

1) Final revision and publication of four papers on Lagrangian analysis and assimilation in realistic regional ocean models and application to in-situ Argo data (Taillandier et al., 2006a,b, Taillandier and Griffa, 2006, Veneziani et al., 2007).

2) Implementation of Lagrangian assimilation in a coastal model using in-situ drifter data and submission of a paper (Taillandier et al., 2007, in revision)

3) Development and implementation of a new method to parameterize subgrid scale processes for particle transport simulations, and publication of a paper (Haza et al., 2007)

4) Participation in a Marine Rapid Environmental Assessment (MREA) experiment in a coastal area of the Mediterranean Sea. Indications on drifter release strategy have been provided and analysis of data sets of tracer and surface velocity are planned.

5) Publication of the Lagrangian Analysis and Predictability of Coastal and Ocean Dynamics (LAPCOD) book by the Cambridge University. The editors are A. Griffa, A. Mariano, D. Kirwan, T. Özgökmen and T. Rossby.

RESULTS

i) Lagrangian data assimilation in coastal models: application to in-situ drifter data.

In the previous years of the grant, assimilation methods for Lagrangian data have been developed and implemented in realistic regional models. In this last period the more challenging application to coastal models, including high inhomogeneity and competing scales of motion, has been considered.

The assimilation has been performed in a coastal area of the central Adriatic Sea, a sub-basin of the Mediterranean Sea, using data from surface drifters and outputs from a state of the art model (ROMS) during the experiment DOLCEVITA in 2002. The area is especially challenging since it is characterized by a swift boundary current (Western Adriatic Current, WAC) flowing along the shelf with high shear and by an interior flow with high variability and intense mesoscale activity. The same region has also been studied in the framework of another recent experiment, the Dynamics of the Adriatic in Real Time DART06, where additional drifters have been launched in the boundary current and in the interior. We focused on the exchange between the WAC and the interior which is expected to play an important role in the ecology of the area, since the WAC advects the water of the Po River, rich in nutrients, therefore heavily influencing productivity. The WAC is subject to significant instability, especially in the considered area which is strongly topographically controlled and characterized by the presence of a cape (the Gargano Cape), leading to intrusions in the interior flow.

The assimilation is based on a variational approach that optimally blends model outputs and Lagrangian data (Taillandier et al., 2006a). It has been applied for a period of 45 days between October 1 and November 15 2002, when there is good drifter coverage of the WAC in the vicinity of the Gargano Cape, providing a time series of corrected velocities (estimates). Several diagnostics have been used to evaluate these estimates. In the previous methodological and numerical work of Taillandier et al (2006a), estimate errors have been quantitatively evaluated using the "twin

experiment" approach, where synthetic data are considered and the true state of the ocean is assumed known. Here, since in-situ data are used and the real ocean state is not known, the errors cannot be computed directly, and a hierarchy of indirect tests is introduced to evaluate the results. The first set of tests addresses the internal consistency and the impact of the assimilation, based on the comparison between results from the estimates and results from the "first guessed" fields, i.e. the original ROMS fields without drifter corrections. The tests include a particle prediction diagnostic and two statistics characterizing the transport in terms of residence times in various regions and export rates from the WAC toward the interior. The results show that the assimilation is quite effective. The error on the particle prediction is significantly reduced and tends to saturate (Fig.1), showing that the method is internally consistent since the assimilation is obtained minimizing the differences between observed and simulated trajectories. The residence times and export rates diagnostics appear significantly impacted by the analysis, and indicate an improvement over the first guess with respect to the measured quantities.
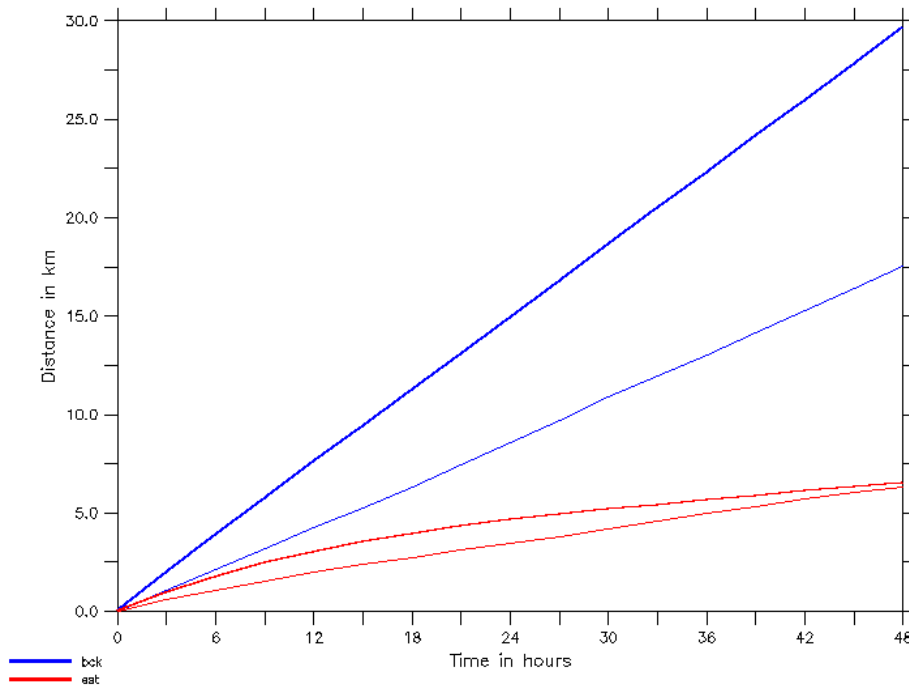
Figure 1: Distance (error) between observed drifter positions and trajectories simulated inside first guessed (estimated) velocity fields on a 48 hour forecast, in blue lines (red lines). Average (in solid lines), and standard deviation (in thin lines) are computed over the whole data set. (from Taillandier et al., 2007). The error is significantly reduced for the estimates.

Another test is based on a qualitative comparison with data from the MODIS satellite images. The comparison is necessarily qualitative given the intrinsic differences between the drifter information (relative to the upper 1-2 m of water and filtered) and the image information (relative to an instantaneous surface tracer not completely passive). For these reasons, the comparison does not focus on the detailed structure of the field, but rather on the main characteristics of the WAC and its exchange with the interior. An example of results is shown in Fig.2, for the day October 27. The image (Figure 2a) shows large instabilities occurring in the WAC, and two clear patterns of export at the tip of the cape. This event occurs during a period dominated by Sirocco wind (from South-East), and in
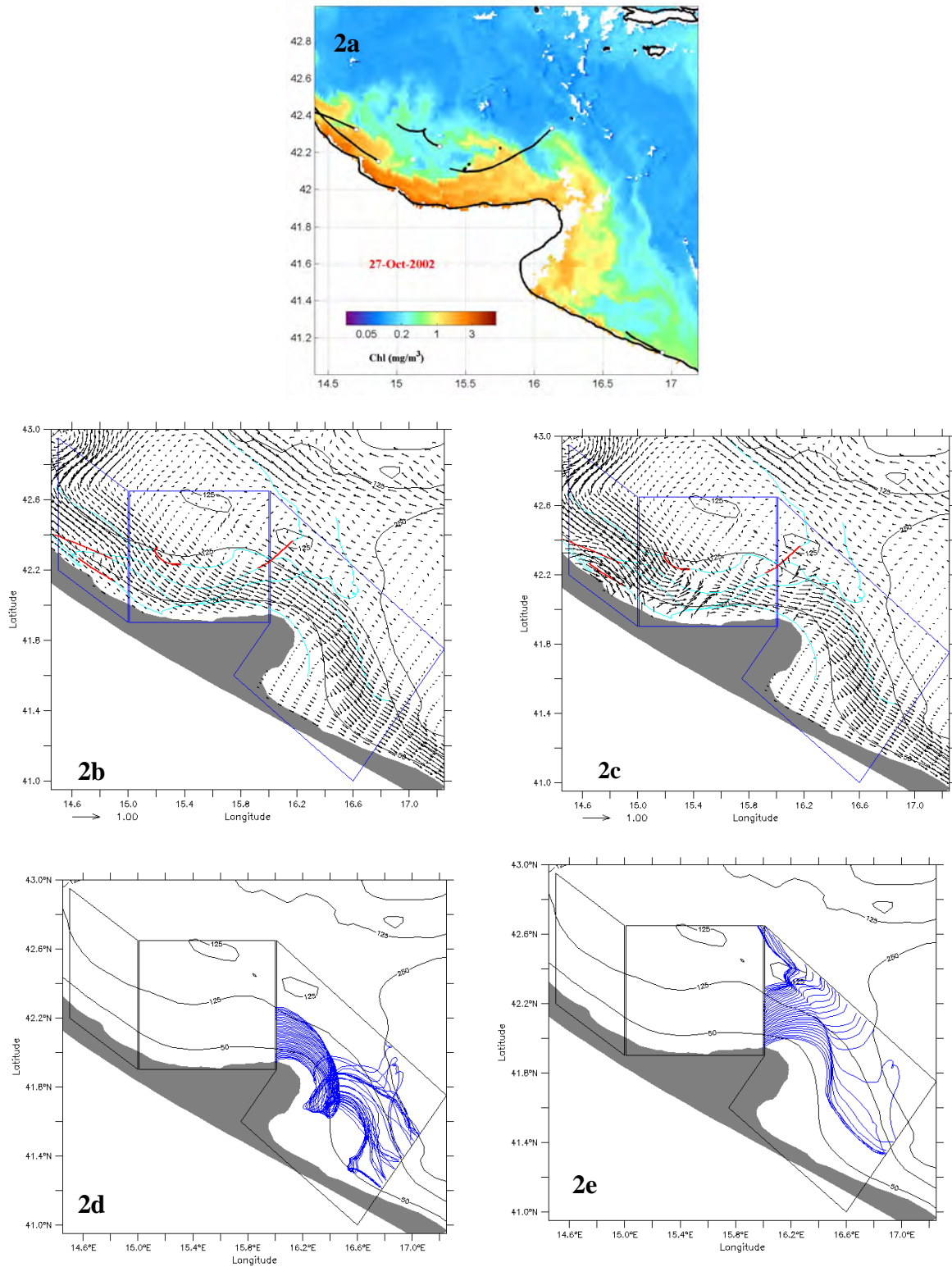
Figure 2: a) sea surface color from MODIS satellite taken at day October 27 2002, with current drifter positions in white circles and low-pass filtered drifter track segments for the previous 3 days;b) and c) mean surface circulation over days 26-27 for the first guessed and estimated velocity fieldsrespectively; d) and e) trajectory simulations inside the first guessed and estimated velocity fields respectively for the launching time day 26.

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particular during a brief intermediate episode of southward wind. Four drifters sample the zone, three upstream the cape in the boundary current and one showing a clear exit path from it. A comparison between the first guessed and estimated velocity (Figures 2b,c) shows that the assimilation creates an eddy structure upstream the cape and an offshore plume close to the tip. The pattern of the numerical trajectories is significantly different for the first guess and the estimate (Figures 2d,e). First guess trajectories stay inside the boundary current, recirculating downstream the cape, while the estimate trajectories show a marked exit point at the tip, in keeping with what shown in the image (Figure 2a). In summary, the assimilation appears to significantly improve the description of the boundary current regime with respect to the ROMS model first guess, capturing its main features when sampled by the drifters.

ii) Development and implementation of a subgridscale parameterization for particle transport

Forecasting of the Lagrangian pathways of particles in the ocean necessarily relies on the accuracy of the ocean and coastal models. However, these models include a number of errors that come from incomplete knowledge of forcing, smoothing of scales, as well as limitations in the resolved physics (for instance circulation models are usually hydrostatic and use parameterizations to describe mixing processes). These errors propagate directly from the Eulerian velocity field to the Lagrangian transport, significantly affecting particle paths and dispersion. Since circulation models are computationally expensive and will continue to contain similar errors in the foreseeable future, an important question is how to improve their Lagrangian transport characteristics in a cost-effective and realistic manner.

We have addressed this problem developing a so-called Lagrangian sub-grid-scale or LSGS model that acts directly on the diagnostics of particle transport computed from circulation models (Haza et al., 2007). The LSGS supplies a correctional velocity vector in the Lagrangian transport equation that minimizes the discrepancy between the statistical behavior of the modeled (synthetic) and real (observed) trajectories in terms of variance and time scales. The LSGS method has been derived theoretically in the context of a random-flight model and first tested using a simplified turbulent model using Markov velocity fields.

The LSGS has then been implemented in a realistic high resolution model applied to a complex coastal flow, i.e. the Navy Coastal Ocean Model (NCOM) configured in the Adriatic Sea. The model is subject to realistic forcing from (4km COAMPS) winds, tides and river runoff and coupled to a coarser resolution global model. The performance of the LSGS is tested using an approach conceptually similar to the "twin experiment" approach, i.e. assuming that the statistics of the real trajectories are known and testing how the statistics of model trajectories corrected using the LSGS compare with the real ones. Two regions are selected with a high ratio of eddy to mean kinetic energy to maximize the effect of turbulent fluctuations on the dispersion of particles and away from the boundaries to avoid strong statistical inhomogeneity. Despite the general complexity of the flow patterns, reasonably good results are obtained using the LSGS. Given the difficulty of capturing exactly the turbulent fields, the use of such LSGS models in particle transport routines associated to circulation models appears to be a necessary and promising avenue.

iii) Participation in MREA experiments

In June 2007, we have participated in a Marine Rapid Environmental Assessment (MREA) experiment, in collaboration with NURC-NATO, NRL, OGS, CNR (Italy) and LSEET-University of Toulone (France). The experiment is called LASIE (Ligurian Air Sea Interaction Experiment) and

includes also a coastal component focused on the Gulf of La Spezia (POET, Predictive Oceanographic Environmental Trial).

During the experiment, a number of drifters have been released in clusters of 3-5 units, with average initial distance of approximately 1 km or less. This launching strategy is expected to be very useful for the ODDAS-DRI purposes, since it allows to investigate the properties of drifting arrays and of their dispersion. In particular, since the initial distance between drifters is small, we will be able to study processes of dispersion at various scales, from submesoscale to mesoscale and up. Two main areas have been chosen for successive cluster launches. One area is in the open Ligurian Sea, next to a moored buoy (ODAS buoy) with meteo-marine sensors, while the other area is much closer to the coast, in the Gulf of La Spezia. In this way, the effects of coastal dynamics and smaller scale processes can be specifically investigated.

Examples of trajectories launched in the Ligurian Sea are shown in Fig.3a, exhibiting a very interesting behaviour. During the first 2-3 days the drifters move together, maintaining the cluster structure, and then they suddenly separate moving in different directions. In other cases (not shown) the drifters stay close to each other for longer times, up to a week, and then they appear to suddenly disperse as they get close to the coast. The reasons for these sudden bursts of separation and their implications for mixing events will be studied. The more coastal trajectories are shown in Fig.3b. These drifters were launched in "catch and release" mode by P.Poulain, with missions of 1 to 2 days. Most of the drifters maintained close to each other during mission, either moving swiftly when caught by the current or slowly dispersing in more calm days. Only one cluster, which stayed in the water for slightly longer time (2 days), showed a pattern of strong and sudden dispersion.

During the next year of the grant we plan to analyze the drifter data in collaboration with P.Poulain (OGS) and M. Rixen (NURC), using also outputs from NCOM model in collaboration with G. Peggion (NRL). We will investigate the possibility of enhancing Lagrangian predictability assimilating some of the drifters in the cluster, a strategy that can be envisioned for ODDAS puroposes.
The MREA data will also provide us with a great opportunity to start investigating methods for data fusion, simoultaneously considering drifter data, satellite tracer data and other surface velocity data. We have an ongoing collaboration with L. Piterbarg (USC) focused on the development and implementation of simoultaneous data assimilation and data fusion. During the coastal POET experiment, a VHF Radar WERA data set has been collected by A. Molcard (LSEET-University of Toulone). The data are presently processed and compared with the drifter and other in situ data, showing great potential. We are planning to collaborate with A. Molcard on this topic.
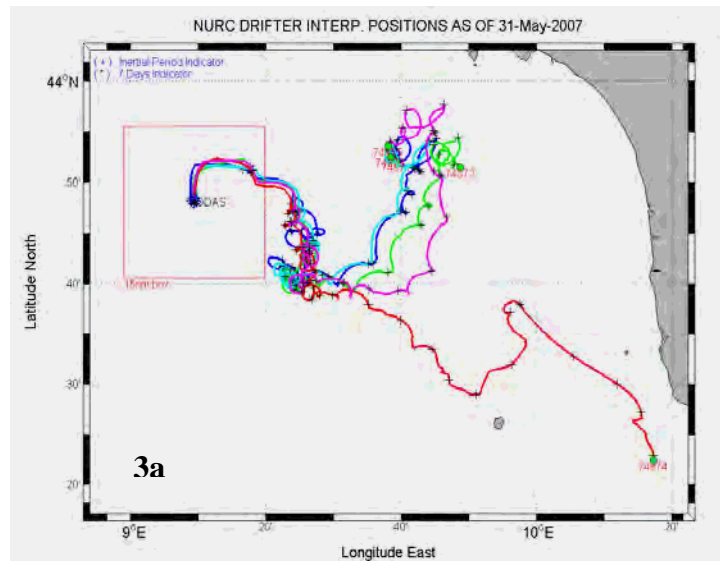
Figure 3: a) trajectories of a cluster of 5 drifters launched in the Ligurian Sea; b) trajectories of 5 clusters of drifters launched in the Gulf of La Spezia during the period June 16-28 2007. The white (orange) triangles indicate launching (ending) points. Courtesy of P.Poulain (OGS)

IMPACT/APPLICATIONS

The results on Lagrangian data assimilation have a significant impact for operational systems. They provide additional value to Argo floats and gliders, which usually provide TS data for assimilation, and to drifters especially for coastal applications. The sub-grid-scale parameterization appears to be a promising avenue to improve particle transport modeling in a cost-effective and realistic manner.

RELATED PROJECTS

1) Statistical and stochastic problems in Ocean Modeling and Prediction, ONR, PI: L.Piterbarg, N00014-99-1-0042.

2) Predictability of particle trajectories in the ocean, ONR, PI: T.M. Özgökmen, N00014-05-1-0095.

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